Chapter 6
Mercury in Surficial Sediments

6.1 Introduction

6.1.1 Background

Sediments can be a reservoir of trace contaminants. This is true for mercury, which is strongly attached to particles in the water column and settles to the lake bottom along with the particles to become the building blocks of the sediment. Surficial sediment particles enriched in mercury may be resuspended by currents and waves and transported by currents to new locations. Eventually a particle with its associated mercury is buried by particles deposited at a later date. Once the particle ceases to physically interact with the water column, it becomes a part of the permanent sediment record.

From the standpoint of mass balance modeling, those particles that can be resuspended and transported elsewhere within the lake are of interest. Contaminants associated with these particles are subject to transport, creating a flux of materials from one location in the lake to another location in the lake. These surficial sediment particles are also subject to interactions with the food chain, resulting in contaminant exposures to organisms.

6.1.2 Study Objectives

With respect to mercury in sediments, the LMMB Study was designed to describe the horizontal variability of mercury in the surficial sediments of Lake Michigan (Figure 6-1). By agreement among principal investigators of the sediment, surficial sediments were defined as the surficial 1 cm of sediment. Based upon experience, it was decided that this was the depth of sediment most likely available for resuspension. To ascertain the character of resuspended sediments, sediment trap samples were also collected at a number of locations in the lake (Figure 6-2). The locations were to be representative of depositional and non-depositional locations. The specific objectives of the sediment mercury study were to:

- Document concentrations of mercury in surficial sediments,
- Describe the horizontal variation of mercury in surficial sediments,
- Estimate the flux of mercury to the surficial sediments,
- Describe the horizontal variation in mercury fluxes to the surficial sediments, and
- Define the concentration of mercury and its time variation in resuspended sediments.

For Lake Michigan Mass Balance modeling and project objectives, the reader is referred to the modeling and project plans (USEPA, 1995c and 1995d).

Figure 6-1. Sampling Locations and Type of Sample Recovered between 1994 and 1996

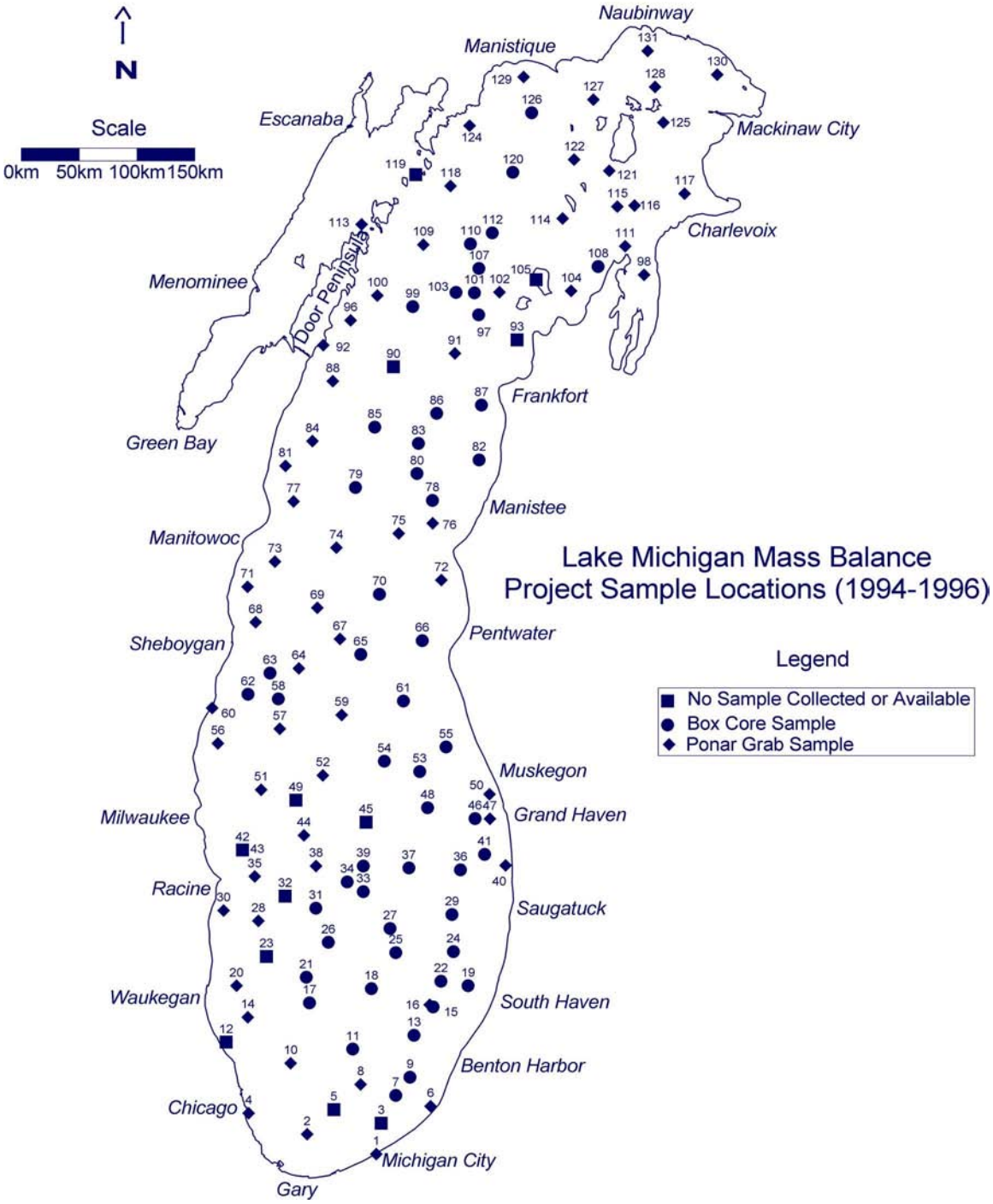
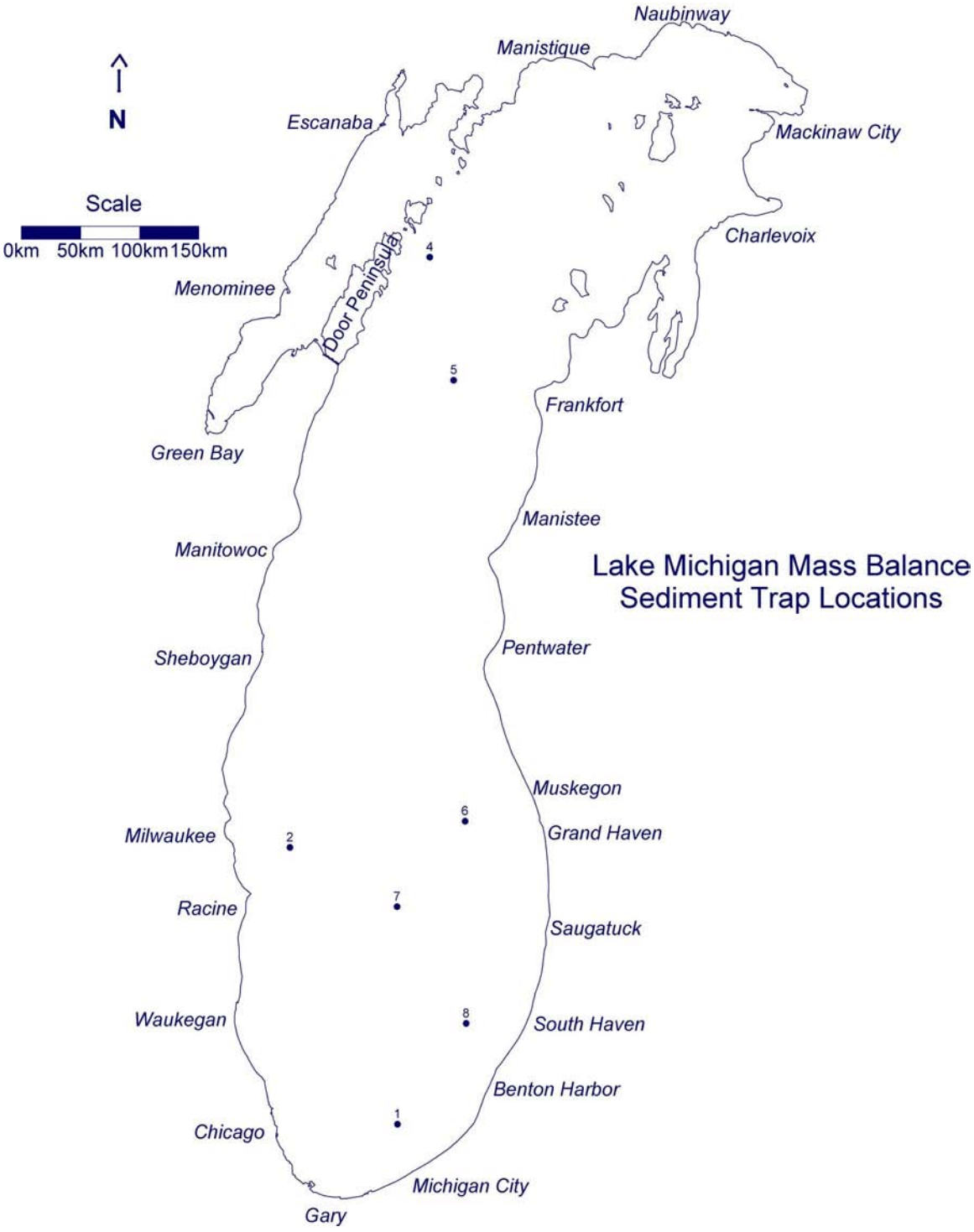


Figure 6-2. Sediment Trap Locations



6.2 Results

6.2.1 Mercury in Surficial Sediments

Surficial sediments were collected using the box corer and Ponar grab sampling techniques (Section 2.4.4). From July 18, 1994 to May 22, 1996, at least one surficial sediment sample was collected at each of 118 stations, for a total of 126 samples (Table 6-1). (Note: The station numbers used for the sediment sample collection effort do not correspond to the station identifiers used for the open-lake water samples described in Chapter 5).

At six stations, both a Ponar grab sample and box core sample were collected; and at another single station, one Ponar grab sample and two box core samples were collected. When more than one sample was collected at a given station using both the Ponar grab and box core devices, the result from the box core sample was used in the data analysis provided in this report because box-coring was the preferred sampling method (see Section 2.4.4). The mean mercury concentration in Lake Michigan surficial sediments was 0.078 mg/kg and the median value was similar (0.079 mg/kg) (Table 6-2).

Table 6-1. Concentrations of Mercury for each Lake Michigan Surficial Sediment Station

Station Number*	Hg Concentration (mg/kg)	LMMB Sample Number
1	0.018	sd1p
2	0.0074	sd2p
4	0.033	sd4p
6	0.006	sd6p
7	0.072	942356
8	0.074	sd8p
9	0.092	942321
10	0.021	sd10p
11	0.040	sd11p
13	0.10	940532
14	0.012	sd14p
15	0.10	940608
16	0.096	sd16p
17	0.14	284
18	0.12	940659
19	0.088	940152
20	0.020	sd20p
21	0.24	940285
22	0.13	940590
24	0.15	940011
25	0.13	943564
26	0.11	951475
27	0.15	940143
28	0.032	sd28p
29	0.17	940102
30	0.036	sd30p

Table 6-1. Concentrations of Mercury for each Lake Michigan Surficial Sediment Station

Station Number*	Hg Concentration (mg/kg)	LMMB Sample Number
31	0.11	950164
33	0.12	943117
34	0.19	951426
35	0.011	sd35p
36	0.14	941861
37	0.10	941802
38	0.11	sd38p
39	0.22	942545
40	0.003	sd40p
41	0.15	943106
43	0.011	sd43p
44	0.050	sd44p
46	0.14	942472
47	0.032	sd47p
48	0.14	942412
50	0.016	sd50p
51	0.018	sd51p
52	0.019	sd52p
53	0.15	942190
54	0.12	942959
55	0.15	941965
56	0.012	sd56p
57	0.084	sd57p
58	0.13	950648
59	0.036	sd59p
60	0.006	sd60p
61	0.17	951452
62	0.11	941233
63	0.14	951795
64	0.10	sd64p
65	0.14	942019
66	0.17	950451
67	0.049	sd67p
68	0.006	sd68p
69	0.013	sd69p
70	0.16	950461
71	0.008	sd71p
72	0.012	sd72p
73	0.022	sd73p
74	0.016	sd74p
75	0.086	sd75p

Table 6-1. Concentrations of Mercury for each Lake Michigan Surficial Sediment Station

Station Number*	Hg Concentration (mg/kg)	LMMB Sample Number
76	0.13	sd76p
77	0.012	sd77p
78	0.14	952700
79	0.15	941148
80	0.12	940829
81	0.020	sd81p
82	0.14	940402
83	0.18	951686
84	0.034	sd84p
85	0.15	951283
86	0.14	951271
87	0.14	940399
88	0.034	sd88p
89	0.028	sd89p
91	0.14	sd91p
92	0.006	sd92p
95	0.26	sd95p
96	0.0045	sd96p
97	0.15	951877
98	0.012	sd98p
99	0.13	950097
100	0.007	sd100p
101	0.13	951858
102	0.029	sd102p
103	0.12	943042
104	0.008	sd104p
106	0.011	sd106p
107	0.12	951823
108	0.16	950698
109	0.004	sd109p
110	0.10	952550
111	0.005	sd111p
112	0.14	952533
113	0.15	sd113p
114	0.034	sd114p
115	0.023	sd115p
116	0.006	sd116p
117	0.026	sd117p
118	0.007	sd118p
120	0.11	952569
121	0.011	sd121p

Table 6-1. Concentrations of Mercury for each Lake Michigan Surficial Sediment Station

Station Number*	Hg Concentration (mg/kg)	LMMB Sample Number
122	0.012	sd122p
123	0.006	sd123p
124	0.004	sd124p
125	0.002	sd125p
126	0.15	950880
127	0.006	sd127p
128	0.012	sd128p
129	0.002	sd129p
130	0.016	sd130p
131	0.041	sd131p

* The station numbers used for the sediment sample collection effort do not correspond to the station identifiers used for the open-lake water samples described in Chapter 5.

Table 6-2. Summary Statistics for Lake Michigan Surficial Sediment Mercury Concentrations

Descriptive Statistic	Result
Mean Concentration (mg/kg)	0.078
Standard Deviation of Mean (mg/kg)	0.065
Median Concentration (mg/kg)	0.079
Minimum Concentration (mg/kg)	0.002
Maximum Concentration (mg/kg)	0.260
Number of Observations	118

To visually display the results, all data were contoured using a linear variogram with no drift kriging. In order to contour mercury concentrations in surficial sediments, it was necessary to assign a concentration to the boundary of the lake as well as to locations from which sediment samples could not be recovered. This boundary concentration was set at 0.0035 mg/kg, the average mercury concentration measured in sand that was relatively free of silt- and clay-sized particles. For contouring fluxes, the net mercury flux chosen for the boundary was 1.2 ng/cm^2/y (Rossmann 1999, Rossmann and Edgington 2000), the estimated regional atmospheric flux of mercury. Without other processes operative, this would be the flux to locations along the shoreline. While these assumptions are oversimplifications (especially in areas impacted by local high fluxes of mercury), the selected boundary conditions represent the most reasonable values that can be obtained without additional data.

6.2.2 Mercury in Sediment Trap Samples

Resuspended sediments were collected using sediment traps (Section 2.3.4). A total of 65 samples from 7 different traps, representing 5 stations, were analyzed for total mercury. Sixteen trap samples from one station having two traps could not be analyzed due to the use of mercury chloride as a preservative. Results for each trap are contained in Table 6-3. (Note: The station numbers used for the sediment trap sample collection effort do not correspond to the station identifiers used for either the sediment core samples in Table 6-1 or the open-lake water samples described in Chapter 5). Approximately 50% of all results had a mercury concentration <0.5 mg/kg. Mercury concentrations at 30 m water depth were highest at Station 7 and were lowest at Station 5 (Table 6-4).

Table 6-3. Concentrations of Mercury in Sediment Trap Samples

Station Number*	Trap Number	Sequence Number	Trap Water Depth (m)	Sample Number	Mercury Concentration (mg/kg)
7	5	2	30	ST314	27
7	5	9	30	ST321	6.1
7	5	10	30	ST322	4.2
7	5	11	30	ST323	4.8
7	5	12	30	ST324	2.9
7	5	15	30	ST327	3.9
7	5	16	30	ST328	2.2
7	5	17	30	ST329	5.8
7	5	18	30	ST330	6.9
7	5	23	30	ST335	11.
7	4	2	155	ST337	1.6
7	4	3	155	ST338	3.0
7	4	4	155	ST339	2.4
7	4	5	155	ST340	2.0
7	4	6	155	ST341	0.95
7	4	7	155	ST342	3.0
7	4	8	155	ST343	1.8
7	4	9	155	ST344	1.1
7	4	10	155	ST345	0.47
7	4	11	155	ST346	0.47
7	4	12	155	ST347	0.38
7	4	13	155	ST348	0.42
7	4	14	155	ST349	0.43
7	4	15	155	ST350	0.40
7	4	16	155	ST351	0.33
7	4	17	155	ST352	0.44
7	4	18	155	ST353	0.66
7	4	19	155	ST354	0.51
7	4	23	155	ST358	1.4
8	7	1	30	ST359	1.1
8	7	2	30	ST360	0.30
8	7	3	30	ST361	0.37
8	7	4	30	ST362	0.36
8	7	5	30	ST363	0.21
8	7	9	30	ST367	0.66
8	7	10	30	ST368	0.91
8	7	11	30	ST369	0.55
8	7	12	30	ST370	0.32
8	7	13	30	ST371	0.43
8	7	14	30	ST372	1.2
8	7	15	30	ST373	2.5

Table 6-3. Concentrations of Mercury in Sediment Trap Samples

Station Number*	Trap Number	Sequence Number	Trap Water Depth (m)	Sample Number	Mercury Concentration (mg/kg)
8	7	16	30	ST374	0.44
8	7	18	30	ST376	1.2
8	7	20	30	ST378	0.64
8	7	21	30	ST379	2.5
8	7	23	30	ST381	1.2
2	9	1	77	ST382	0.30
2	9	7	77	ST385	0.71
8	6	1	51	ST388	0.39
8	6	2	51	ST389	0.61
8	6	3	51	ST390	0.42
8	6	4	51	ST391	0.27
1	8	1	45	ST395	0.31
1	8	2	45	ST396	0.44
5	3	3	30	ST469	0.79
5	3	4	30	ST470	0.42
5	3	10	30	ST476	0.53
5	3	11	30	ST477	0.24
5	3	12	30	ST478	0.27
5	3	13	30	ST479	0.22
5	3	14	30	ST480	0.22
5	3	15	30	ST481	0.25
5	3	16	30	ST482	0.55
5	3	17	30	ST483	0.84
5	3	18	30	ST484	0.43

* The station numbers used for the sediment trap sample collection effort do not correspond to the station identifiers used for either the sediment core samples in Table 6-1 or the open-lake water samples described in Chapter 5.

Table 6-4. Mercury Summary Statistics for each Station at each Depth for Sediment Trap Samples

Station	Depth (m)	Number of Samples	Mean (mg/kg)	Standard Deviation (mg/kg)	Median (mg/kg)	Minimum (mg/kg)	Maximum (mg/kg)
1	45	2	0.37	NA	0.37	0.31	0.44
2	77	2	0.51	NA	0.51	0.30	0.71
5	30	11	0.43	0.23	0.42	0.22	0.84
7	30	10	7.5	7.4	5.3	2.2	27
7	155	19	1.1	0.90	0.66	0.33	3.0
8	30	17	0.87	0.69	0.64	0.21	2.5
8	51	4	0.42	0.14	0.40	0.27	0.61

It should be noted that the mass of sediment collected from the traps was often too small to complete all analyses targeted in the LMMB Study. Samples were collected and analyzed for mercury only in those cases where the amount of material available in trap samples was sufficient, and this generally

corresponded with periods of high sediment fluxes. Because of these shortcomings in the data set at this time, the authors do not wish to interpret the sediment trap any further.

6.2.3 Moisture Content of Sediment Samples Collected by Ponar

The moisture content ([wet weight - dry weight]/[dry weight] x 100) was measured on each Ponar sample received (Table 6-5). Ponar samples were collected not only from those regions with bottoms too hard to core, but also from areas inaccessible to the ship. Most of these areas were very sandy. A few were very silty sands.

Table 6-5. Moisture Content of Samples Collected by Ponar

Station Number*	LMMB Sample Number	Moisture Content (%)
1	sd1p	25
2	sd2p	22
4	sd4p	24
6	sd6p	22
8	sd8p	70
9	sd9p	67
10	sd10p	31
11	sd11p	53
13	sd13p	76
14	sd14p	32
16	sd16p	43
19	sd19p	88
20	sd20p	30
28	sd28p	44
30	sd30p	53
35	sd35p	26
36	sd36p	75
38	sd38p	65
40	sd40p	22
43	sd43p	24
44	sd44p	52
47	sd47p	40
50	sd50p	28
50	sd50p	23
51	sd51p	42
52	sd52p	44
56	sd56p	32
57	sd57p	52
59	sd59p	52
60	sd60p	23
64	sd64p	74
67	sd67p	52
68	sd68p	27
69	sd69p	31

Table 6-5. Moisture Content of Samples Collected by Ponar

Station Number*	LMMB Sample Number	Moisture Content (%)
71	sd71p	26
72	sd72p	23
72	sd72p	22
73	sd73p	47
74	sd74p	42
75	sd75p	64
76	sd76p	74
77	sd77p	28
81	sd81p	23
84	sd84p	54
88	sd88p	27
89	sd89p	32
91	sd91p	78
92	sd92p	20
95	sd95p	63
96	sd96p	23
98	sd98p	24
98	sd98p	27
100	sd100p	22
102	sd102p	36
104	sd104p	25
106	sd106p	27
109	sd109p	22
111	sd111p	25
111	sd111p	23
113	sd113p	90
114	sd114p	26
115	sd115p	37
116	sd116p	30
117	sd117p	69
118	sd118p	22
121	sd121p	20
122	sd122p	27
123	sd123p	24
124	sd124p	21
125	sd125p	24
127	sd127p	38
128	sd128p	34
129	sd129p	18
130	sd130p	33
131	sd131p	68

* The station numbers used for the Ponar sample collection effort do not correspond to the station identifiers used for the open-lake water samples described in Chapter 5.

Because these data are only for Ponar samples collected from primarily sandy areas, the mean and median moisture contents are relatively low compared to silt- and clay-rich sediments (Table 6-6). The minimum of 18% moisture represents a fairly pure sand, while the maximum of 90% moisture represents a very silt- or clay-rich sand that might even be classified as a silt or clay.

Table 6-6. Summary Statistics for Moisture Content Analyses of Samples Collected by Ponar

Descriptive Statistic	Result
Mean Moisture Content (%)	39
Standard Deviation of Moisture Content (%)	19
Median Moisture Content (%)	31
Minimum Moisture Content (%)	18
Maximum Moisture Content (%)	90
Number of Samples	75

6.2.4 Mercury Fluxes to Sediments

Because sedimentation rates have been measured at all box-core stations (Edgington and Robbins 1997b, Robbins and Edgington 1997), mercury fluxes were calculated for each site (Table 6-7). The flux is equal to the Pb-210 sedimentation rate times the mercury concentration. At locations where box cores could not be collected, the net sedimentation rate is essentially zero; hence, the net flux is also zero. With a mean of 7.2 ng/cm^2/y, mercury fluxes ranged between 0.85 and 32 ng/cm^2/y (Table 6-8).

Table 6-7. Net Mercury Flux to Lake Michigan Surface Sediments

Station Number*	Total Hg Flux (ng/cm²/y)	Station Number*	Total Hg Flux (ng/cm²/y)
7	6.4	54	0.94
9	19	55	31
9	2.3	58	4.8
13	3.8	61	18
15	23	62	1.1
17	1.4	63	4.0
18	2.2	65	1.6
19	8.4	66	6.2
21	2.9	70	14
21	3.9	78	2.8
22	17	79	5.8
24	10	80	2.8
25	4.5	82	13
26	2.2	83	6.4
27	4.7	85	3.8
29	6.0	86	4.4
31	3.2	87	16
33	2.0	97	3.2
33	3.8	99	5.2
34	5.0	101	7.5
36	8.1	103	3.3

Table 6-7. Net Mercury Flux to Lake Michigan Surface Sediments

Station Number*	Total Hg Flux (ng/cm²/y)	Station Number*	Total Hg Flux (ng/cm²/y)
37	2.7	107	5.4
39	8.5	108	8.0
41	32	110	2.6
46	6.5	112	9.4
48	0.85	120	8.0
53	1.9	126	7.1

* The station numbers used for the sediment sample collection effort do not correspond to the station identifiers used for the open-lake water samples described in Chapter 5.

Table 6-8. Summary Statistics for Net Mercury Fluxes to Lake Michigan Surface Sediments in Depositional Basins

Descriptive Statistic	Result
Mean Net Mercury Flux (ng/cm^2/y)	7.2
Standard Deviation of Mean Net Flux (ng/cm^2/y)	6.9
Median Net Mercury Flux (ng/cm^2/y)	4.9
Minimum Net Mercury Flux (ng/cm^2/y)	0.85
Maximum Net Mercury Flux (ng/cm^2/y)	32
Number of Samples	54

6.2.5 Horizontal Variation of Mercury and Mercury Fluxes

Mercury concentrations and their resulting fluxes varied with location in the lake. Mercury concentrations were higher along the eastern side of the lake than its western side (Figure 6-3). Mercury concentration contours were coincident with those for the bathymetry of the lake (Figure 6-4). Unlike the concentration contours, those for mercury flux were not coincident with the lake bathymetry (Figure 6-5). Regions of highest flux were compressed along the eastern side of the lake.